AN
OSCILLOGRAPH
INVESTIGATION
OF
COMMUTATION

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AN OSCILLOGRAPH INVESTIGATION OF COMMUTATION.

With Special Reference to the Effect of Interpoles upon the Commutating Conditions.

A Thesis
Presented to the Faculty of Armour Institute of Technology
for the Degree of
Electrical Engineer.

by
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Ithaca, New York.
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In the design of all direct current dynamo machinery, and also the alternating current commutator motor, the problem of preventing sparking at the commutator is one of fundamental importance. During the greater part of a revolution of the armature of a direct current machine, the only current flowing in the coils is the armature current, due to the load and directly proportional to it. But when two adjacent commutator segments pass under a brush, the armature coil which is connected between those segments is short circuited by the brush. During the time of this short circuit the current in the coil must fall to zero, reverse, and rise again to its original value in the opposite direction. But at the time of the reversal of the current in the coil, the self induction of the coil comes into play, and resists the reversal of the current. This is caused by the electromotive force of self induction of the coil, known in dynamo design as the reactance voltage. It is this reactance voltage, due to the self induction of the coil, which produces sparking at the commutator.

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In order then, to obtain sparkless commutation, it will be evident that the effect of this reactance voltage must be overcome. This may be done by supplying an external field which shall produce an electromotive force in the coil which is equal to the reactance voltage, but opposite in direction. It will be perfectly clear that a direct current machine of standard design, commutating on the neutral plane, could never meet this condition, and hence sparking must always occur. And so it has become quite common practice, in operating machines of standard design, to shift the brushes backward or forward from the neutral plane, according as the machine is operating as a motor or as a generator. Thus the commutating plane is brought into a field which is opposite in direction to the current in the coil at the instant when commutation takes place. As the coil cuts across this "reversing" field, as it is frequently called, an electromotive force is induced in it, which is opposite in direction to the reactance voltage. Thus the cause of sparking is removed, and the commutation greatly improved. The angle through which the brushes must be shifted will depend upon the current to be reversed, which depends upon the load. Hence as the load increases, the brushes must be shifted farther and farther from the neutral plane.

But this method of preventing sparking is open to many serious objections, and is a poor makeshift at best, particularly in variable speed machines. One of the greatest difficulties in the way of making use of this method for the prevention of sparking is the magnetic effect of the current in the armature coils. This current produces a cross magnetism through the core of the armature the effect of which is to distort the magnetism of the main field, causing a crowding of magnetic lines of force under the trailing pole corners, and a weakening of the field under the leading pole corners. Evidently, this effect will increase with the load, until the trailing pole corner becomes completely saturated, and the field under the leading pole corner reduced to zero or even reversed. If the machine is operating as a motor, the magnetic conditions under leading and trailing pole tips will be just the reverse of what they are in a generator. Under such conditions, no amount of shifting of the brushes will improve the commutation, because the field under the weakened pole corner has been reduced to zero, or reversed, in which condition the E.M.F. induced in the coil by this field will assist the reactance voltage instead of opposing it.

An attempt has been made to reduce the effect of this armature reaction by making the armature very weak and the

field very strong, so that the distorting effect of the armature would be small. This helps the conditions somewhat but does not cure them, and besides the armature is very large for its output. With such a design of machine a carbon brush of high resistance is used, which also helps some in reducing the sparking. But by such a method, sparking is only reduced and not done away with entirely, and so it offers no solution of the problem.

It is clear that in order to obtain sparkless commutation, the effect of the armature reaction, in distorting the main field of the machine, must be done away with. This has been attempted, with varying success, by a number of investigators, but the best practical solution of the problem is probably the one presented by Professor H. J. Ryan. His plan is to do away entirely with the magnetic effect of the armature by surrounding it with a winding which should have the same number of ampere turns as the armature, but opposite in direction. This winding is placed in holes just back of the pole surfaces, and the winding on each pole surface contains the same number of ampere turns as the corresponding part of the armature. These "balancing coils", as they are called, are connected in series with the armature, and thus the magnetic effect of the armature is at all times just balanced by the magnetic effect of the balancing coils. Thus the distorting

of the main field of the machine is prevented, and the commutation very greatly improved.

But a consideration of what takes place during commutation will make it plain that even the balancing coils do not produce ideal commutating conditions, especially when the machine is to be subject to wide variations of load and speed. As was stated above, when commutation takes place, the current in the coil must fall to zero, reverse and rise again to its original value in the opposite direction. Hence commutation should take place in a reversing field; that is, a field opposite in direction to the current which is to be reversed. Furthermore, this reversing field should be proportional to the current in the coil at the time of reversal, that is, proportioned to the load on the machine. In order to obtain this reversing field at the commutating plane, the brushes must be shifted from the neutral plane, through an angle which is proportional to the load. Hence such a machine will not commutate satisfactorily through wide variations in the load. If the machine be a motor, subject to wide and sudden fluctuations in the load, the commutation will be unsatisfactory in spite of the balancing coils.

In order to meet this condition of wide and sudden variations in the load, it is evident that a "commutating field" must be supplied. In order to make it clear just

what is meant here, the expression "commutating field" will first be defined. By commutating field is meant a field which shall be at all times proportional to the load; its position must be such that the armature coils will be passing through it at the time of commutation, and it should be practically constant in value. In direction this commutating field is opposed to the direction of the current in the armature coils at the time of commutation. Such a field will give sparkless commutation at all loads, because it is always of such a magnitude and direction as to produce an electromotive force which will exactly reverse the current in the coil at commutation.

To meet this condition and provide a commutating field, small auxiliary poles called interpoles are used, placed midway between the poles of the main field, with the pole faces covering the region of commutation. In order to produce the necessary commutating field, these interpoles are provided with the proper number of turns of wire, and connected permanently in series with the armature. Thus when the load on the machine is heavy, the number of ampere turns on the interpoles is large and a strong commutating field is produced. On the other hand, when the load is light, the number of ampere turns on the interpoles is low and a weak commutating field is the result. Thus the strength of the commutating field varies with the load

until the point of saturation of the interpoles is reached, which is well above the point of normal operation of the machine. Since we are not dealing with a straight line in the saturation curve of the interpole core, it is evident that the interpole field will not be, at all times,exactly proportional to the load. But the qualities of the carbon brush admit of a considerable variation of the interpole field with respect to the load, without any effect upon the commutation.

In order to show the effect of the interpoles upon the field distribution of a motor, the following figures are presented.

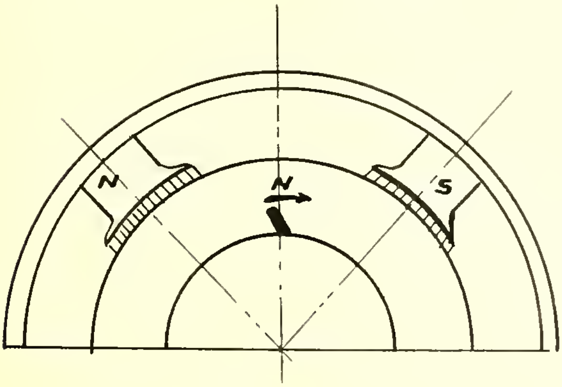

Fig. 1

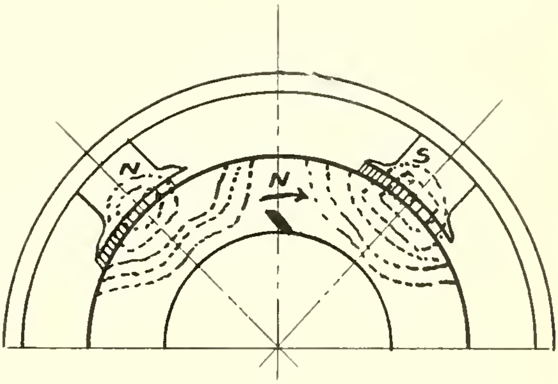

Fig. 2

Figure 1 above shows the field distribution of a constant speed motor, running under no load. It will be noted that the field distribution across the pole face is practically constant. When a load is thrown upon the machine, the magnetic effect of the current in the armature at once appears. This armature reaction weakens the field

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strong enough to overcome the field produced by the armature, and in addition produce a commutating field. This commutating field is powerful or weak, in proportion to the load on the machine, and is entirely independent of the field of the main poles. Even although the armature reaction may produce an extreme distortion of the field across the face of the main poles, this will not affect the commutation, because the proper field is present at the commutating plane.

One important point in interpole motor design may properly be noted in this connection. Since the fringe of the main field is no longer required for commutating purposes, the bevel on the pole faces may be made quite narrow. In motors of ordinary design this bevel must frequently be made quite wide in order to give a wide fringe for commutation, resulting in a loss of valuable pole face area and tending to increase the speed of the motor. When the interpole construction is used, the main pole could be made rectilinear if it were not for the humming of the armature teeth. If the width of the bevel be made equal to the width of a tooth and a slot, the fringing of the field will be sufficient to overcome all tendency of the teeth to vibrate.

The object in view in the experimental work presented in this paper is a study of the electromotive force condi-

tions in the coils of a direct current motor, at the time of commutation, when any particular coil is undergoing short circuit by the brush. When the current in a coil is reversed at commutation, the inductive electromotive force produced by such reversal causes a distortion of the normal open circuit electromotive wave of the machine. Hence, if this distorted wave is obtained experimentally, and carefully compared with the normal open circuit wave, the amount of the distortion may be determined, and so also the magnitude, relatively at least, of the electromotive force of commutation. It is by a study then, of the electromotive force waves obtained from a single coil of the machine, and a comparison of these waves with the open circuit waves, that the electromotive force of commutation is to be studied.

As has been already said, various methods have been devised to reduce the electromotive force of commutation, and so improve the commutation and reduce the sparking at short circuit. In carrying out the experimental work here described, the work has been limited entirely to a study of the effect of interpoles upon the commutating conditions. By examining the electromotive force curves of a single coil of the motor, first with the interpole windings connected, and then with them disconnected, the effect of the interpoles upon the form of the electromotive curve

may be obtained, from which the effect of the interpoles upon the electromotive force of commutation becomes apparent. Briefly stated then, the experimental work presented here is a study of the effect of interpoles upon the electromotive force of commutation, through an examination of the electromotive waves as obtained from a single coil of the machine.

The machine which was used in this work is a Lincoln Interpole Motor, of variable speed type, rated at 3 H.P. output. It is intended to operate on 110 volts, when it will draw 25 amperes at full load. The speed range lies between 500 R.P.M. and 2200 R.P.M., and the operation is equally satisfactory at all speeds within this range. The speed variation is obtained by having the motor armature movable, through a range of about 4" in the direction of the shaft. This is done by making the motor ball bearings movable in the bearing supports in the motor frame. A cam, acting in a slot in the shaft, and controlled by a hand wheel, produces the motion of the armature. In the normal position of the armature it is directly under the field poles, and the minimum speed is obtained. As the armature travels out from under the field poles, the effect is to decrease the effective length of conductor, and hence the speed must be greater to produce the same counter electromotive force. In the extreme position of the armature,

the effective length of conductor is less then one half the total length.

The main field of the machine is a shunt field of four poles, the normal shunt field current being 1.8 amperes on 110 volts. The interpole field consists of two poles, placed diametrically to each other. There are four carbon brushes and each brush will cover two commutator segments, thus short circuiting two coils at the same time. There are 111 commutator segments, and since the impressed electromotive force is 110 volts, the maximum value of the electromotive force per coil is 4.25 volts.

Since the work in hand requires a study of the electromotive force curve of a single coil of the motor, it was necessary to provide a connection between one of the coils and the galvanometer of the oscillograph. This was done by placing two small copper rings on the end of the commutator spider just outside the copper bars. These two rings were then connected to two adjacent segments of the commutator. Small copper brushes were then provided to run on the little copper rings, and from these brushes leads were taken to the coils in the galvanometer of the oscillograph. In all, four rings were placed upon the machine in the manner described, the electromotive force rings being connected as explained, and the two current rings being con-

nected in series with one coil of the armature and the current coil of the galvanometer. From this second pair of rings the current wave was obtained, in the same manner as the electromotive force wave. As stated above, these small collector rings were mounted on shoulders on the commutator body, the electromotive force rings being placed on a shoulder outside the commutator bars at the extreme end of the commutator, and the current rings on a shoulder inside the bars of the commutator. The space on which these rings were placed is quite narrow, the shoulder being about 5/8" in width. The scheme used for mounting these rings is as follows:- A ring of red fibre 5/8" in width, was turned up on the lathe, of such a diameter as to make a snug driving fit on the shoulder on the commutator spider. Two grooves 1/8" wide and 3/16" deep, were then turned in the outside of the fibre ring, the distance between the grooves being about ¼". A bar of copper, 1/8" x 1/8" was used to form the collector rings, being wound into the grooves in the fibre ring, the ends beveled off and soldered together. The fibre rings were then driven on to the shoulders on the commutator, where it was found they were held tightly in place by the contraction of the fibre after it had become thoroughly dried and seasoned. The armature was then placed in the lathe and the rings

trued up. The fact that the rings did not slip when the cutting tool was applied showed that the fit was good.

The brushes which were used to collect the current from these rings, were made from strips of sheet copper, .009" thick, 3/32" wide, and 1¾" long. Each brush consisted of eight such strips, placed one upon the other, and soldered together at one end. In order to give the brush greater stiffness, a strip of copper .027" thick was soldered upon the back; this backing strip was 1/8" wide and 1¼" long. Thus the brush proper extended ½" beyond the end of the backing strip, to give sufficient flexibility to the end of the brush.

Inasmuch as the armature of this motor is movable in the bearings, it was necessary to provide a brush holder which should be carried on the shaft bearings proper, which, as stated above, are movable in the large bearings in the motor frame. This was done by bolting a wooden yoke to the end of the shaft bearing, and supporting on this yoke the wrought iron rods which carry the collector brushes. These rods are ¼" x ¼", and are simply fastened to the wooden yoke which supports them by means of wood screws. The brushes are soldered to the ends of these carrying rods, the brush being at right angles to the rod. By such an arrangement as this the brushes followed the collector rings through any axial movement of the armature.

The oscillograph used in these experiments was designed by Mr. H. J. Hotchkiss, and built by Mr. Fred Fowler, mechanician in the department of physics, Cornell University. A detailed description of the instrument will be found in the Physical Review, Vol. 8, page 152. Only a brief description will be given here, setting forth the principal features of the oscillograph. The essential part is an extremely sensitive galvanometer needle, suspended in the field of a permanent magnet. This needle consists of a very small piece of soft iron, mounted on one side of a quartz fibre, with a mirror about one half the size of the iron on the other side. This quartz fibre is stretched across a quartz bow, and the bow is mounted in a slot, milled in the side of a brass pin. This brass pin is slipped into a hole in the magnet yoke, and the galvanometer needle is thus suspended in the field of the permanent magnets. The small piece of soft iron then takes up a position parallel to the lines of force of the magnet field. Two coils of wire are placed, one in front of this galvanometer needle, and one behind it. These two coils are connected together, either in series or in parallel. When a current flows through these two coils, a field is set up at right angles to the field of the permanent magnets. The needle then assumes a position corresponding to the position of the resultant of these two magnetic

fields. Now if the current through these two coils be alternating, the resultant field will change in position, first on one side and then on the other, of the axis of the coils. Thus the needle swings back and forth, following very closely this resultant field.

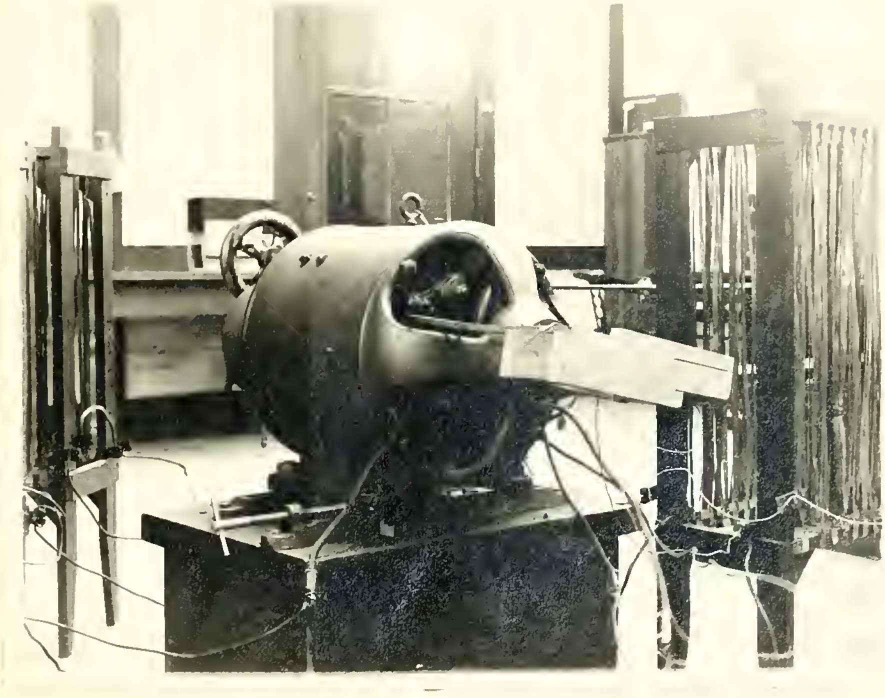
This galvanometer is mounted in a light-tight box, which has a small slit in the side for the admission of a beam of light. The beam of light, supplied by an arc lamp, passes through the slit in the side of the box and falls upon the small mirror of the galvanometer needle. The reflected beam from the mirror is then focused upon a horizontal slit in the opposite end of the containing box. When an alternating current is passed through the coils of the instrument, the galvanometer needle oscillates back and forth, and so the reflected beam of light from the mirror vibrates in a horizontal plane along the slit in the end of the box. If now, a photographic plate be shot down vertically behind this slit, the beam of light will trace a curve upon the plate, the ordinates of the curve being proportional to the amplitude of the oscillation of the galvanometer needle. This was done by providing a slideway, containing a plate holder, with an arrangement for shooting the plate holder down the slide. The holder was driven by a pin bearing upon it at the top, the pin being actuated by a spring.

The following pictures will give some idea of the apparatus used in these experiments. Figure 5 is a picture of the motor with which the experiments were performed, viewed from the commutator end, with the armature in its extreme position; that is, as far out from under the field poles as possible. The yoke for supporting the rods which carry the small collector brushes, as well as the rods themselves, are shown in the picture.

Figure 6 is a picture of the oscillograph with the slide-way, which contains the plate holder, in position. One of the galvanometers has been removed from the box, and is shown at the side. From this picture an idea may be had of the appearance of the permanent field magnets, and also of the coils which carry the alternating current.

Figure 7 is a view of the arc lamps which were used to furnish the light for the galvanometer mirrors. The length of the arc, that is, the space between the carbons, may be varied by turning the large brass screw. The position of the arc may be changed by simply pulling or pushing the screw up or down. It will be noticed that the arc carbons are carried in fibre blocks, and the fibre blocks in turn are bolted to iron lugs. These iron supporting lugs move back and forth on the iron slide which carries them, and may be set in any position by tightening the bolts which clamp them to the slide.

Thus the arc as a whole is movable, and also any one carbon is movable with respect to the others. Two lamps were provided, so that both galvanometers could be used at the same time if desired, one for current and one for electromotive force.



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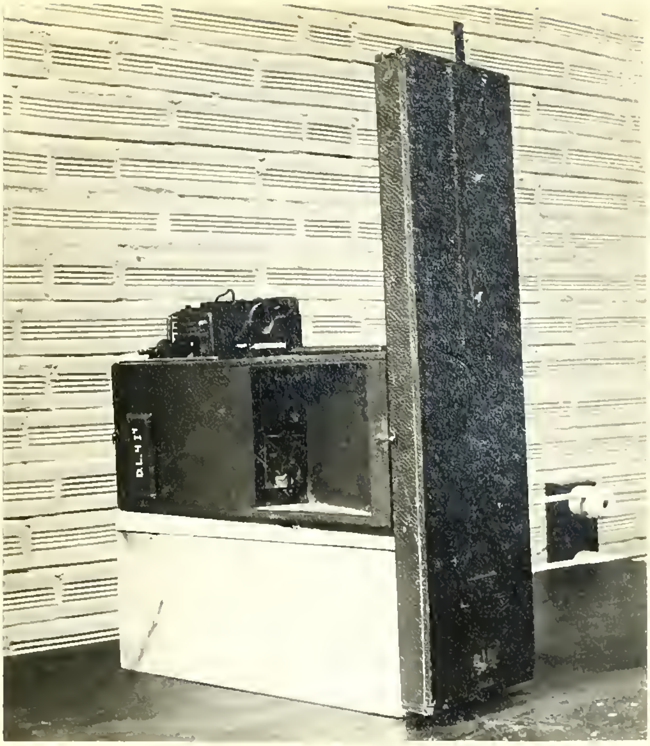

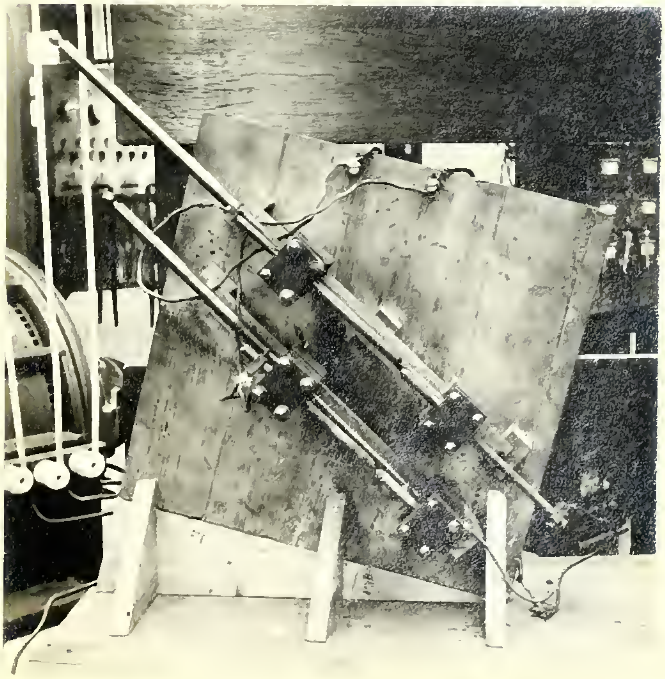

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In examining the oscillograms presented here, it will be seen that the curves do not consist of a single smooth line, but are wavy in outline. Two causes may be assigned for this wavy form of the curves. In the first place, the construction of the oscillograph is such as to make a smooth curve, under the conditions of these experiments, practically impossible. The oscillograph was designed for very high frequencies, hence the moving part, the galvanometer needle, had to be extremely small and light. Furthermore, in order to make the oscillograph sensitive to very small and very rapid variations in the impressed electromotive force, it is necessary that the damping action of the permanent controling magnets should be weak. It must be remembered that the current which was led into the coils of the oscillograph was taken from a brush contact on the small slip rings connected to a single coil of the motor armature. Now unless the brush contact is practically perfect, there will be variations in the contact resistance from time to time, which will cause corresponding variations in the electromotive force impressed upon the galvanometer coils. Several different kinds of brushes were made and tried, until the best results possible were obtained with the brush described above. But a perfect brush contact is well nigh impossible, so that the electro-

motive force impressed upon the coils of the galvanometer varied slightly. The result was that the variations in current caused thereby, set the galvanometer needle to swinging through a small amplitude in its natural period of vibration, which is short. Thus, instead of tracing a smooth curve, the galvanometer gives a wavy curve, the amplitude of the wave depending upon the amount of variation of the current in the coils.

An attempt was made to reduce the amplitude of this wave by mounting the galvanometer needle in a small glass tube, and surrounding it with glycerine. It was found, however, that the viscosity of the oil was not sufficient to materially reduce the vibrations, and also if a heavier oil were used, the amplitude of the fundamental electromotive force wave would be seriously reduced. Also the refraction of the beam of light from the galvanometer mirror, by the walls of the glass tube, was found to spread the beam out in such a way that a well defined curve upon the photographic plate would have been impossible.

However, in the oscillograms presented here, it is thought that the irregular outline of the curves will not in any way impair their usefulness for the purpose in hand, although the appearance is not so good as a smooth curve.

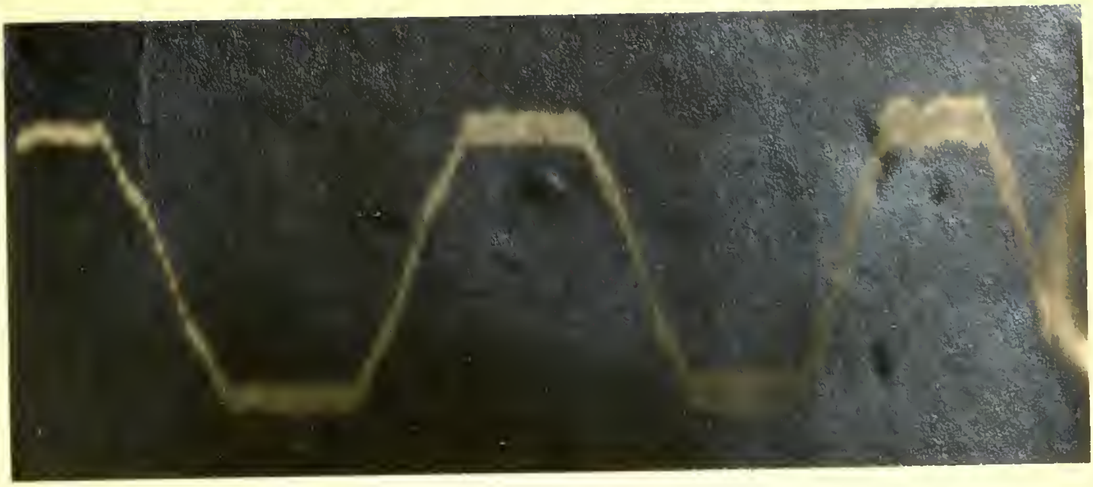

Fig. 8

Figure 8 above is an oscillogram showing the normal electromotive force distribution about the armature of the motor. It was taken with the machine running as a generator on open circuit, at a speed of 800 R.P.M., with the interpole field disconnected. This flat topped wave is what one would expect from any shunt motor of good design. The shunt field was separately excited when this curve was taken, the field current being 1.2 amperes on 110 volts.

When the distribution of electromotive force is as shown in Figure 8, commutation would be good because all effects of armature reaction are absent. Since the function of interpoles is to counteract the effect of armature reaction, and maintain as nearly as possible a normal flux distribution about the armature, it is evident that the

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interpoles should give an electromotive force curve, under load, more closely resembling the no-load curve than is the case when no interpoles are used. It is not maintained that the electromotive force curve under load conditions should exactly resemble the no-load curve, because even when interpoles are used, the magnetic effect of the armature produces a distortion of the flux under the main field poles which will distort the no-load curve. Also, the interpole is not designed to produce a zero field at the commutating plane, but rather a field proportional to the current to be reversed. For these two reasons then, the interpole will not give a no-load electromotive force curve, when there is a load on the machine.

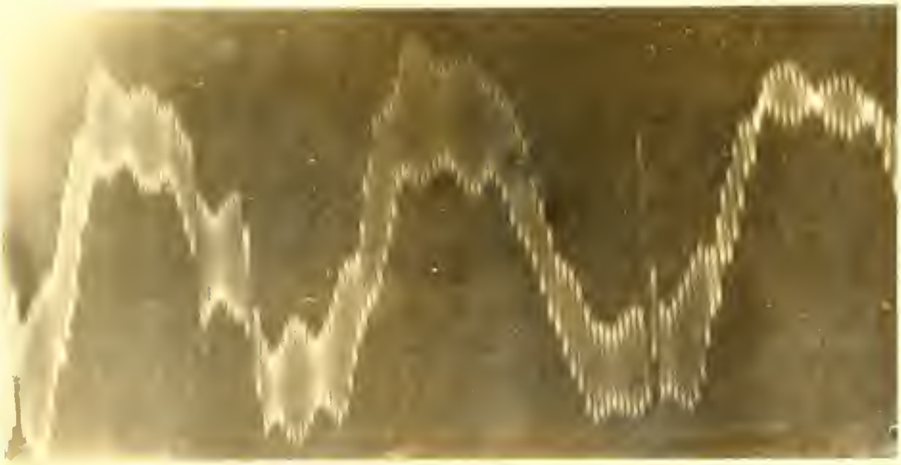

Fig. 9

Figure 9 above is an oscillogram showing the E.M.F. of one armature coil, taken under the following conditions:

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Armature current 25 amperes, full load.

Shunt field current 1.16 amperes.

Speed 920 revolutions per minute.

Electromotive force per armature coil 4.15 volts.

Electromotive force at terminals of oscillograph coils 3.85 volts.

No sparking.

This oscillogram was taken under normal conditions of operation, the interpole field being connected. It will be remembered that the armature of the motor is movable in the bearings in the direction of the shaft, through a space of about four inches. Hereafter the position of the armature when it is under the main poles will be called the normal position and its position at any particular time will be given by stating its distance from the normal position. When the oscillogram shown in Figure 9 was taken, the armature was $2\frac{1}{2}$" from the normal position.

It is seen that this curve is by no means smooth; the reasons for the swinging of the galvanometer needle were given above. However, the general shape of the curve is not difficult to see, and it is plain that it conforms fairly well, in its general shape, to the no-load curve. The tops of the loops, however, indicate that the flux distribution across the main pole faces is not exactly uniform, a condition which the interpoles do not correct.

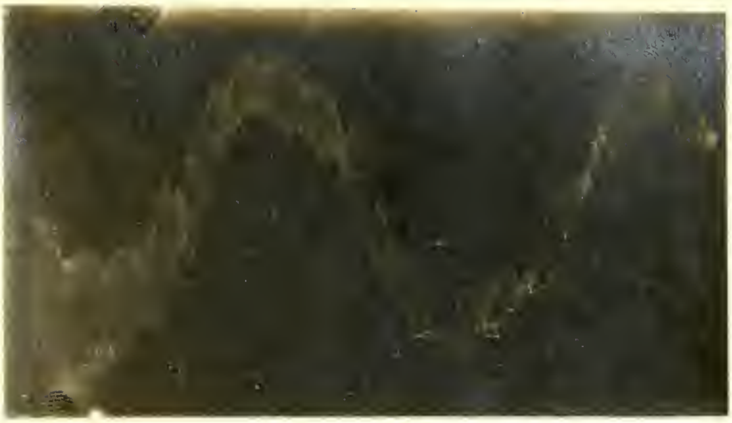

Fig. 10

Figure 10 above is an oscillogram taken under exactly the same conditions as Figure 9, except that the interpole winding was disconnected. The shape of this curve shows a much greater departure from the no-load curve than was apparent in Figure 9. The flux distribution across the main pole face is very different from the no-load distribution, as is shown by the round topped curve. In its general shape, this curve is almost a sine curve, while the no-load curve and also, in a less marked degree, the curve shown in Figure 9, are flat topped curves. These two oscillograms show that the effect of the interpoles is to preserve, to a considerable extent, the no-load flux distribution.

A large number of oscillograms were made under various conditions of load and speed, first with the interpole wind-

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ing connected and then with it disconnected, the object being to show the effect of the interpoles upon the shape of the E.M.F. curve. Several of these curves are presented herewith, although they show very much the same thing as is shown by Figures 9 and 10.

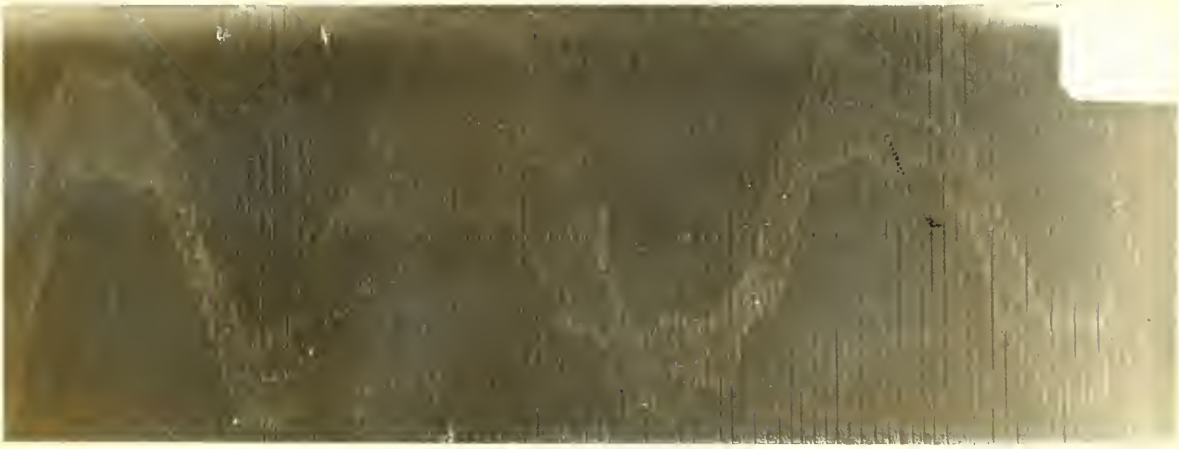

Fig. 11

Figure 11 above shows an oscillogram taken under the following conditions with the interpole winding connected:

Armature current 12.5 amperes, half load.

Shunt field current 1.14 amperes.

Speed 915 revolutions per minute.

Electromotive force per armature coil 4.15 volts.

Electromotive force at terminals of oscillograph coils 3.85 volts.

Armature $2\frac{1}{2}$" from normal position.

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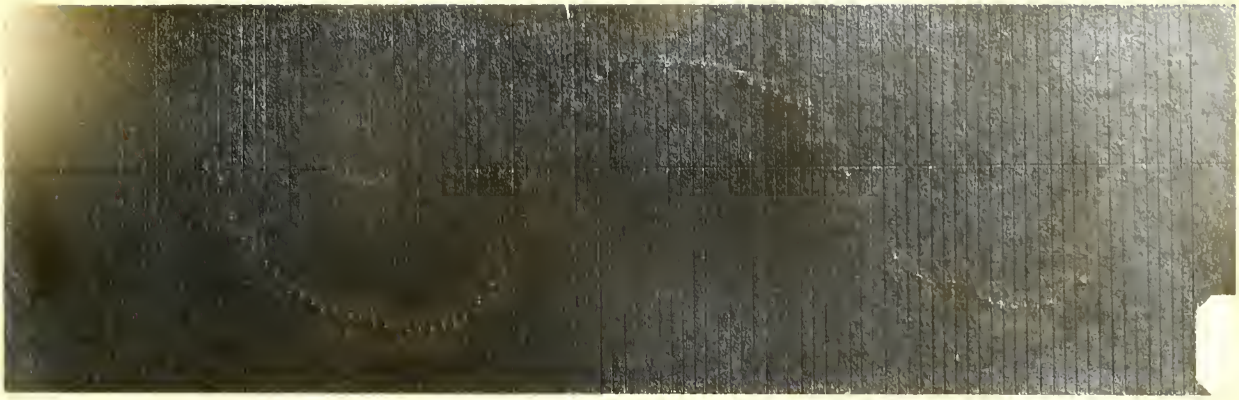

Fig. 12

The oscillogram shown above was taken under the same conditions as Figure 11, except that the interpole field was not connected. In this case, as in the case of Figure 10, discussed above, the sparking at the brushes was bad.

An examination of these two oscillograms will show the same as has been noted in the case of the others already discussed. The curve taken when the interpole field winding was not connected is seen to be much more distorted from the no-load curve than is the case with the curve taken under the same conditions of load and speed, with the interpole winding connected.

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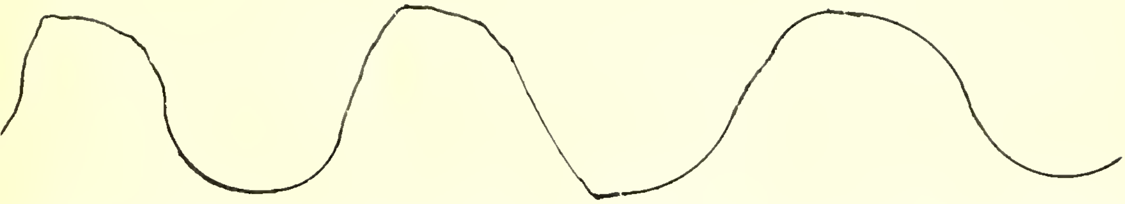

Fig. 13

Figure 13 above is a drawing taken from an oscillogram made under the following conditions:

Armature current 12.5 amperes, half load.

Shunt field current 1.12 amperes.

Speed 990 revolutions per minute.

Electromotive force per armature coil 4.20 volts.

Electromotive force at terminals of oscillograph coils 3.15 volts.

Armature 3" from normal position.

A drawing reproduced from the original oscillogram is shown here instead of the picture itself. This negative was over developed and the print obtained from it was poor. The oscillogram was not made over again because when it was discovered that the negative was poor, the apparatus was

not in such a condition that the conditions given above could be readily duplicated. The drawing given above, however, was made with extreme care from the original negative, and is a faithful reproduction of the curve.

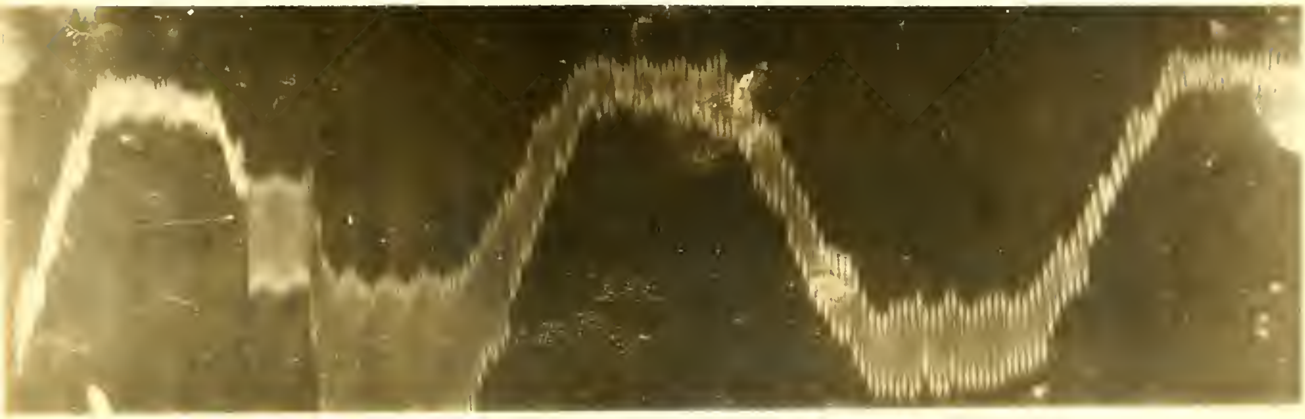

Fig. 14

Figure 14 above is an oscillogram made under the same conditions as Figure 13, except that Figure 14 was made with the interpole winding connected, and Figure 13 with it disconnected. Here again the difference in the shape of the two curves is quite plainly seen. From these oscillograms, and from the others already shown, it is evident that the effect of the interpoles is to give an electromotive force distribution under load which much more closely resembles the no-load distribution than is the case without the interpoles. This means that the interpoles are overcoming the effect of armature reaction, which is just what they are designed

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to do. Twenty oscillograms were taken to show this effect of the interpole field. They were taken under ten different conditions of load and speed, always one with the interpoles and one without them. The result in all of them is the same as in the oscillograms already presented, and hence to prevent a practical duplication of material, no more of them will be presented here.

In any study of commutating conditions, the curve showing the manner in which the current varies in the armature coils is always of interest. When a coil passes under a brush and commutation takes place, the current must fall to zero and then rise to its original value in the opposite direction during the time that its commutator segments are under the brush. If the commutating field is of the proper strength, this reversal of the current should take place promptly, while if a proper commutating field is not provided, the current will decrease gradually to zero and also rise slowly in the opposite direction. This is, of course due to the self induction of the short circuited coil which resists any change in the strength or direction of the current. Several current oscillograms were made, with and without the interpole coils, in an attempt to discover what effect the interpoles might have upon the reversal of the current. The two oscillograms shown below are typical of all that were taken to illustrate this point.

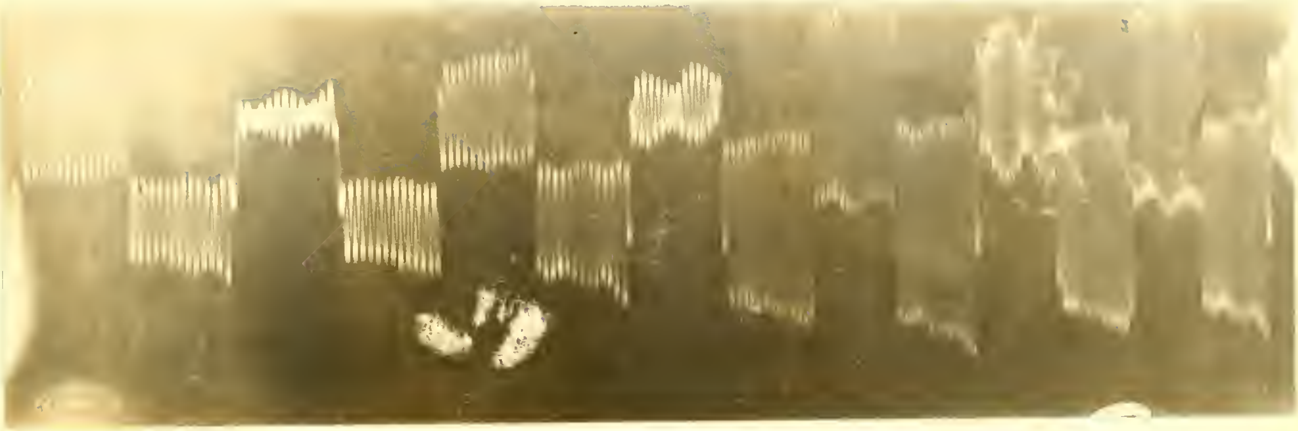

Fig. 15

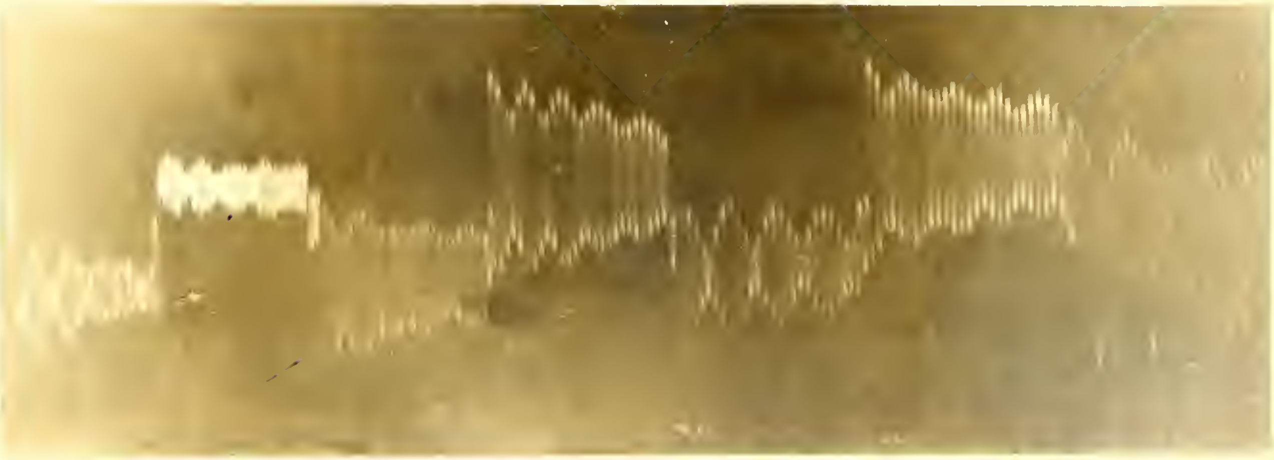

Fig. 16

The oscillograms shown here were taken under the following conditions:

Armature current 12.5 amperes, half load.

Shunt field current 1.16 amperes.

Speed 950 revolutions per minute.

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Current in oscillograph coils 6.25 amperes.

Armature 2.75 inches from neutral position.

In Figure 15 the interpole winding was used, while in Figure 16 it was disconnected. It is seen from these oscillograms that the galvanometer needle of the oscillograph vibrated in its natural period through quite a wide amplitude; this is caused by the fact that quite a large current had to be taken from the small current rings by means of the small copper brushes. The current therefore varied somewhat due to changes in the electromotive force, caused by variations in the brush contact resistance. This causes the needle to swing in its natural period, and produces the very irregular outline of the curves. In general, it was found practically impossible to get good curves with this oscillograph whenever it was necessary to draw any large amount of current through the brushes into the galvanometer coils. A large number of attempts were made to get good current oscillograms on full load, but in every case the outline of the curve was so irregular as to make the oscillogram of very little value. Particularly was this the case when the interpole winding was disconnected.

It will be seen from an examination of the oscillogram in Figure 15 that the reversal of the current takes place promptly, the curve falling in a straight line from a maximum in one direction, through zero, to a maximum in the

opposite direction. It is also seen from the rectangular shape of the curve, that the current is practically constant in value during the time between reversals.

The oscillogram in Figure 16 was made under the same conditions as Figure 15 except that the interpole winding was not used. Here the current does not reverse so promptly as before; this is particularly noticeable at points marked A and B on the oscillogram. It is also seen that the curve does not present the same rectangular outline as in the other case, showing that the current is not nearly so constant between reversals. It appears, then, that the effect of the interpoles upon the current curve is to produce a more prompt reversal of the current than is obtained without them, and also tends to maintain the current constant between reversals, although this effect is not so well marked as the other.

In conclusion, it is seen that the work presented here is simply a study of the effect of interpoles upon the commutating conditions. It appears from the electromotive force curves that the interpoles tend to preserve the no-load form of the curve, by overcoming the distorting effect of the armature reaction. It is not maintained that the no-load curve should be exactly reproduced under load conditions because of a certain amount of field distortion under the main poles, but the contention simply is

that the distortion between the main poles is prevented, as is shown by the load curve more closely following the no-load curve than is the case when the interpole winding is not used.

The current oscillograms show that the interpoles produce a more prompt reversal of the current than when the interpoles are not used. There is no gradual dying away of the current, but a prompt reversal, the current curve following practically a straight vertical line during reversal. The magnitude of the current between reversals is also more nearly constant with the interpoles than without them.

The interpole motor appears to solve the problem of commutation for a machine which must operate under wide variations of speed and load. Such a motor can be used satisfactorily for large machine tool drive, where a speed variation of as much as 300% is required. In all variable speed work, the interpole motor is the only direct current motor which gives good results, especially under conditions where the load and speed do not vary together.

Below are shown three oscillograms which were made after the main part of the work had been finished. These curves were taken with the motor running as a generator on open circuit with a shunt field current of 1.2 amperes. The speed was 800 r.p.m. Also, the interpole winding was given current from an external source, the idea being to see the effect of the interpole field upon the main field under these conditions. Of course these conditions of operation are entirely abnormal, since the interpole winding would have no current in it on no load.

Fig. 17 shows an oscillogram taken under the above conditions, with a current of 3.5 amperes. Fig. 18 shows the curve obtained when the interpole current was 10 amperes, and the curve in Fig. 19 shows the result when the interpole current was 14 amperes.

Since there are only half as many interpoles as main poles, only every other loop is affected. It is seen that the interpole field opposes the field from the main poles, causing the flux to drop almost to zero for a short time. It was found when full load current was passed through the interpole winding that the interpole field was stronger than the main field, and entirely overpowered it.

No particular significance is attached to these curves, but they are presented merely to show something of the intensity of the interpole field as compared to the main field.

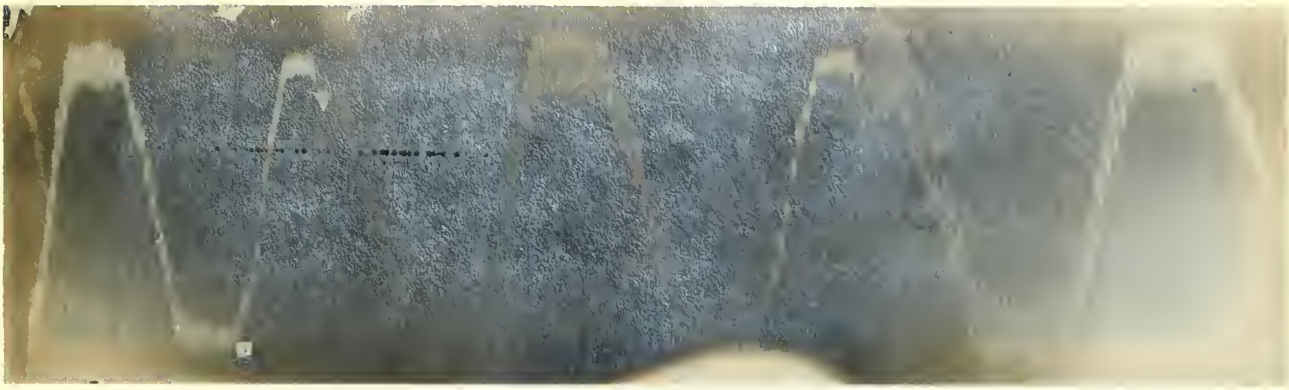

FIG. 17

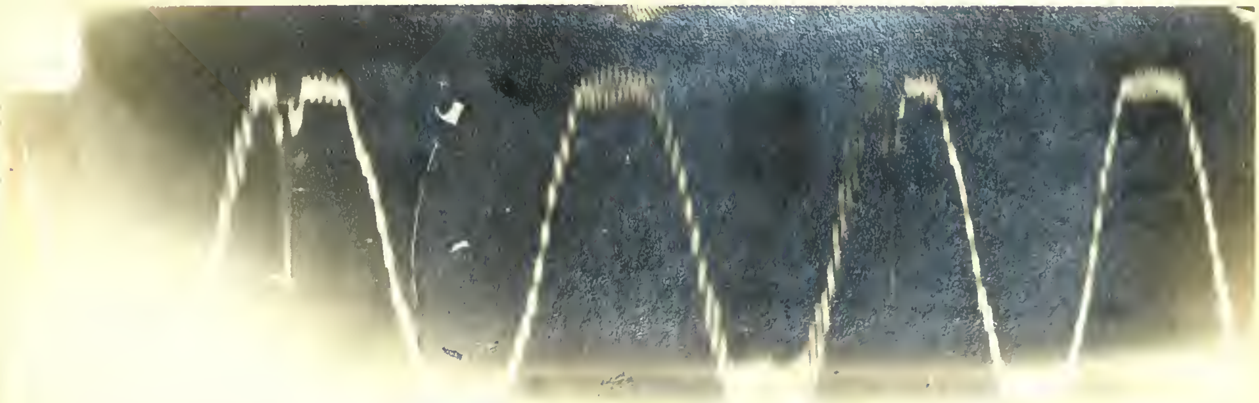

FIG. 18

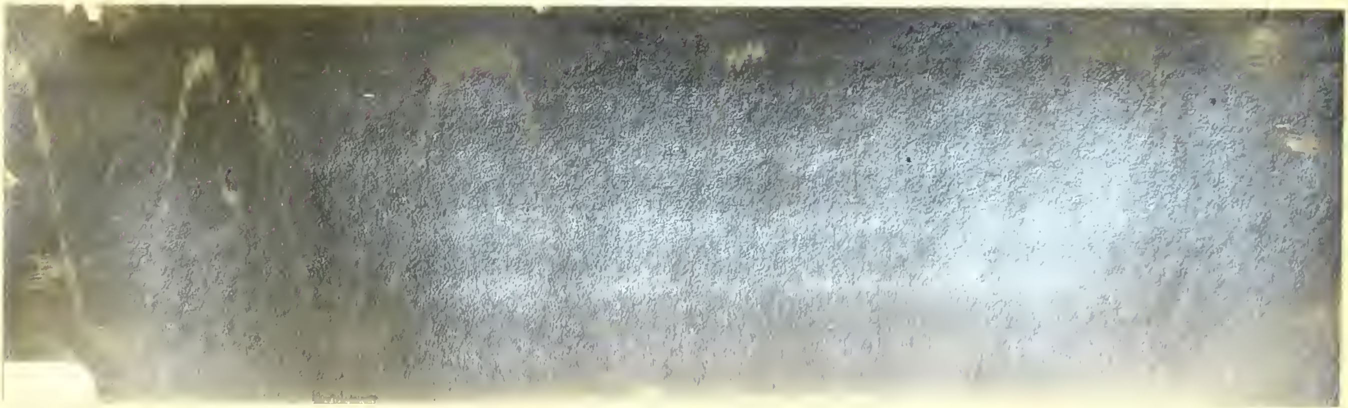

FIG. 19

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